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**Yang et al.**

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(54) **CAPACITOR AND SEMICONDUCTOR  
DEVICE USING SAME**

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**H01L 21/02** (2006.01)

**H01L 29/92** (2006.01)

(52) **U.S. Cl.**

CPC ..... **H01L 29/92** (2013.01)

(58) **Field of Classification Search**

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USPC ..... 257/597

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2008/0203496 A1\* 8/2008 Takahashi ..... 257/409

2010/0109063 A1 5/2010 Hayashida

2010/0252904 A1\* 10/2010 Takahashi ..... H01L 29/063  
257/492

\* cited by examiner

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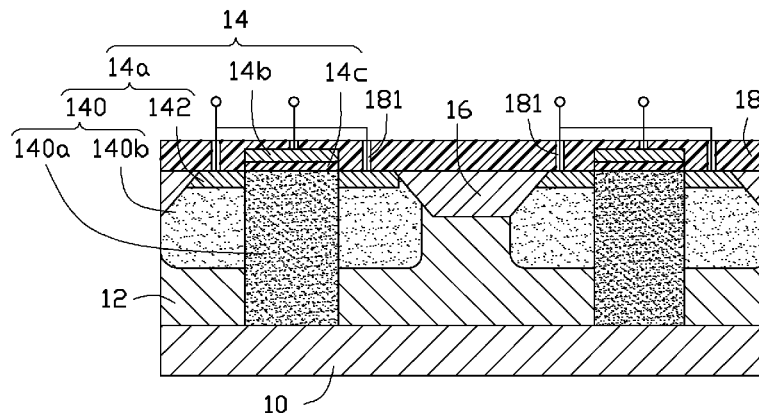
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(57) **ABSTRACT**

A capacitor for a semiconductor device includes a bottom electrode plate, an insulating layer formed on the bottom electrode plate, and a top electrode plate formed on the insulating layer. The bottom plate includes a capacitor well and at least one diffused region formed on the capacitor well. A doping concentration of the at least one diffused region is higher than a doping concentration of the capacitor well, the capacitor well comprising a first well.

**17 Claims, 5 Drawing Sheets**

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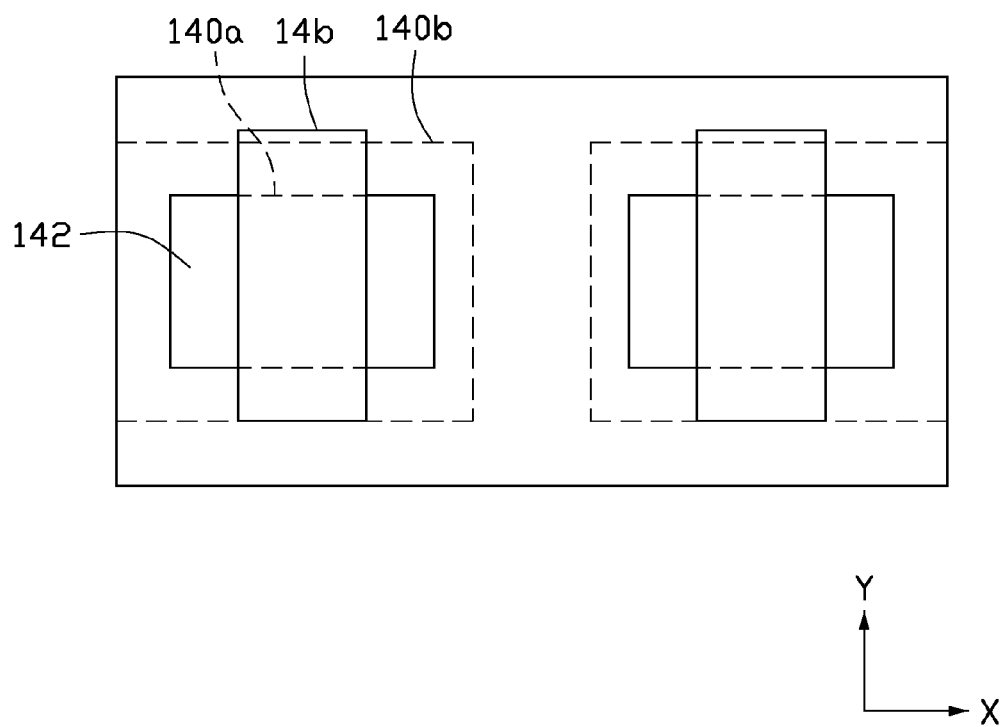


FIG. 2

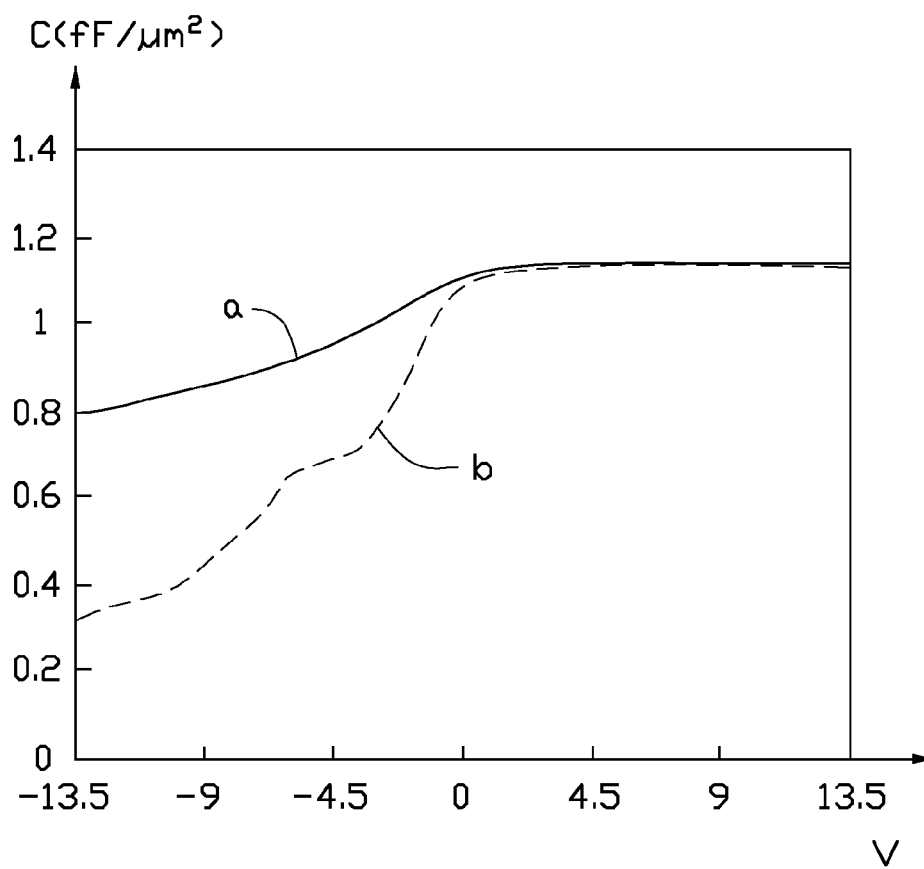


FIG. 3

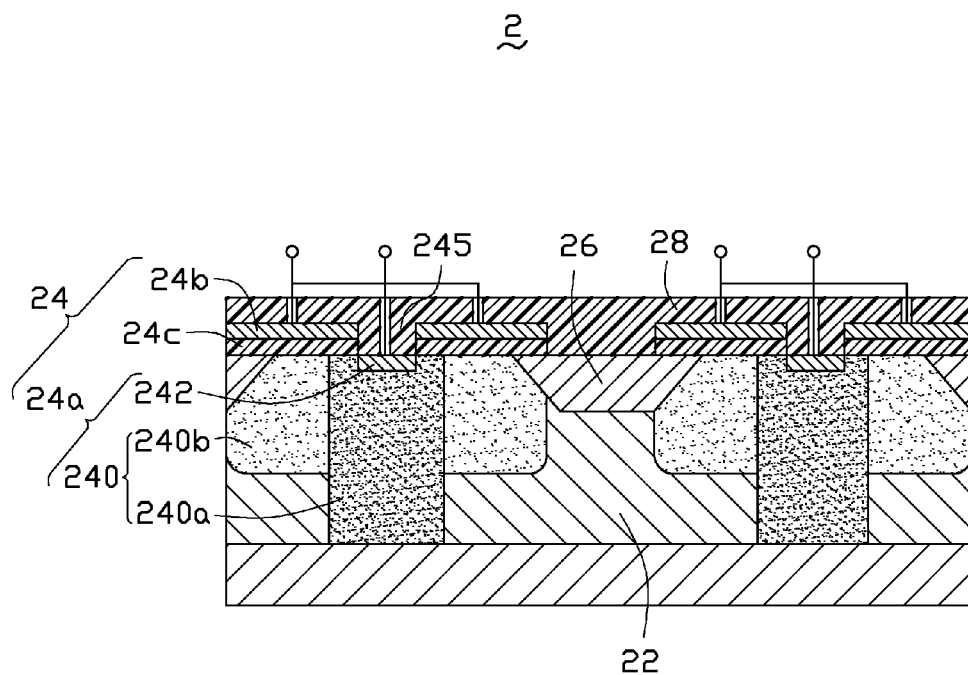


FIG. 4

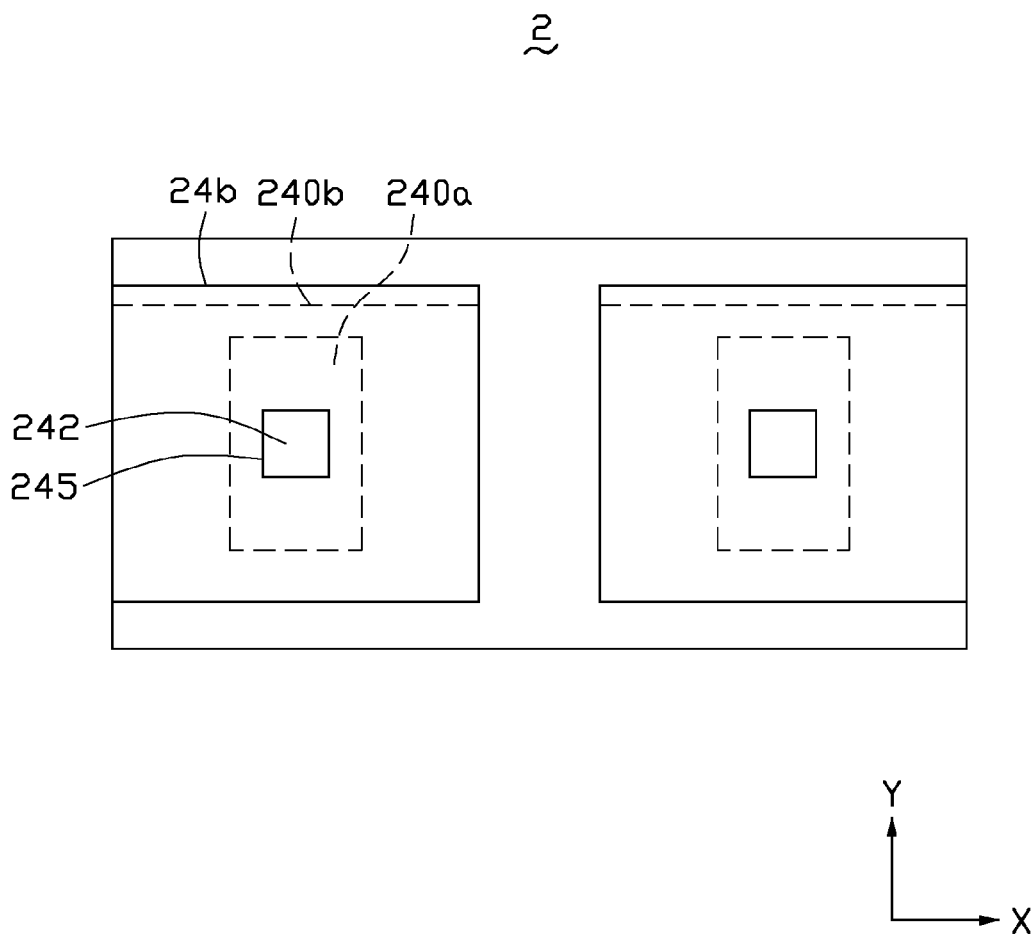


FIG. 5

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# CAPACITOR AND SEMICONDUCTOR DEVICE USING SAME

## BACKGROUND

### 1. Technical Field

The present disclosure relates to a capacitor and a semiconductor device using the capacitor.

### 2. Description of Related Art

A capacitor is capable of receiving high voltages. However, once the capacitor operates in a depletion region and in an inversion region, a capacitance value of the capacitor may be apt to decrease a lot. As a result, quality of the capacitor and an integrated circuit chip employing the capacitor may deteriorate.

Therefore, it is desirable to provide a means which can overcome the above-mentioned problems.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partial perspective illustrating a first embodiment of a semiconductor device including a plurality of semiconductor capacitors, a plurality of isolation elements spacing the semiconductor capacitors, and an insulating layer covering the semiconductor capacitors and the isolation elements according to the present disclosure.

FIG. 2 is a top view of the semiconductor device of FIG. 1 with the isolation elements and the insulating layer of the semiconductor device not being shown.

FIG. 3 is a voltage-capacitance curve of one of the semiconductor capacitors of the semiconductor device of FIG. 1.

FIG. 4 is a partial perspective illustrating a second embodiment of a semiconductor device including a plurality of semiconductor capacitors, a plurality of isolation elements spacing the semiconductor capacitors, and an insulating layer covering the semiconductor capacitors and the isolation elements according to the present disclosure.

FIG. 5 is a top view of the semiconductor device of FIG. 4 with the isolation elements and the insulating layer of the semiconductor device not being shown.

## DETAILED DESCRIPTION

Reference will be made to the drawing to describe specific exemplary embodiments of the present disclosure.

FIG. 1 is a partial perspective illustrating a first embodiment of a semiconductor device 1 according to the present disclosure. FIG. 2 is a top view of the semiconductor device 1. The semiconductor device 1 includes a substrate 10, a common well 12, a plurality of semiconductor capacitors 14, a plurality of isolation elements 16, and an insulating layer 18. The isolation elements 16 and the insulating layer 18 are shown in FIG. 1, but are not shown in FIG. 2. The semiconductor capacitors 14 may be metal oxide semiconductor (MOS) capacitors, for example. The common well 12 is formed on the substrate 10. The semiconductor capacitors 14 are formed on the common well 12. Every two neighboring semiconductor capacitors 14 are spaced from each other by an isolation element 16 and the common well 12. The insulating layer 18 is formed on the semiconductor capacitors 14 and the isolation elements 16. The insulating layer 18 defines a plurality of contact holes 181 penetrating through the insulating layer 18 and positioned above the semiconductor capacitors 14. Each of the isolation elements 16 may

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be a shallow trench isolation (STI) layer, or a filed oxide (FOX) layer, or a combination of the STI layer and the FOX layer, for example.

Each of the semiconductor capacitor 14 includes a bottom electrode plate 14a, a top electrode plate 14b, and an insulating layer 14c formed between the bottom electrode plate 14a and the top electrode plate 14b. The top electrode plate 14b may be a poly-crystal silicon layer, for example. The insulating layer 14c may be a silicon oxide layer, for example.

The bottom electrode plate 14a includes a capacitor well 140 and two diffused regions 142. The capacitor well 140 is formed on the common well 12. The two diffused regions 142 are formed on the capacitor well 140 and are spaced from each other by the capacitor well 140. The two diffused regions 142 may be two double diffused drain (DDD) structures, for example. The capacitor well 140 and the two diffused regions 142 each have a first conduction type. A doping concentration of each of the two diffused regions 142 is higher than a doping concentration of the capacitor well 140. The common well 12 has a second conduction type. The first conduction type differs from the second conduction type.

If the semiconductor capacitor 14 is an n-well capacitor, the two diffused regions 142 are n-type heavily doped regions. The capacitor well 140 is an n-type lightly doped region. The common well 12 is a p-type doped region. That is, the first conduction type is an n conduction type, and the second conduction type is a p conduction type. If the semiconductor capacitor 14 is a p-well capacitor, the two diffused regions 142 are p-type heavily doped regions. The capacitor well 140 is a p-type lightly doped region. The common well 12 is an n-type doped region. That is, the first conduction type is a p conduction type, and the second conduction type is an n conduction type.

The capacitor well 140 includes a first well 140a and a second well 140b. In the present embodiment, the first well 140a penetrates the common well 12 and is formed on the substrate 10. The second well 140b is formed on the common well 12 and surrounds the first well 140a. A doping concentration of the first well 140a is higher than a doping concentration of the second well 140b. The two diffused regions 142 are formed above the second well 140b and are spaced from each other by the first well 140a.

The insulating layer 14c and the top electrode plate 14b are formed on the top of the first well 140a in that order. The top electrode plate 14b and the insulating layer 14c extend along a first direction. The first direction is a direction parallel to a Y-axis of an X-Y plane as shown in FIG. 2. The top electrode plate 14b and the insulating layer 14c completely cover the first well 140a along a second direction perpendicular to the first direction, and do not overlap with the two diffused regions 142 along the second direction. The second direction is a direction parallel to an X-axis of the X-Y plane.

In the present embodiment, the top electrode plate 14b and the insulating layer 14c substantially cover the second well 140b along the first direction. One end of each of the top electrode plate 14b and the insulating layer 14c exceeds the second well 140b, the other end of each of the top electrode plate 14b and the insulating layer 14c is aligned with the second well 140b. A shape and an area of the insulating layer 14c are same with a shape and an area the of the top electrode plate 14b. The edge of the top electrode plate 14b is aligned with the edge of the insulating layer 14c. In alternative embodiments, the top electrode plate 14b and

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the insulating layer **14c** may partially cover the second well **140b** along the first direction, and completely cover the first well **140a** in the X-Y plane.

The top electrode plate **14b** is connected to a first metal layer (not shown) via a contact hole **181** positioned above the top electrode plate **14b**. The two diffused regions **142** are connected to a second metal layer (not shown) different from the first metal layer via two contact holes **181** respectively positioned above the two diffused regions **142**. Accordingly, the two diffused regions **142** are electrically connected with each other.

The doping concentration of the first well **140a** reaches a predetermined doping concentration, to increase the stability of a capacitance value of the semiconductor capacitor **14**. For the semiconductor capacitor **14** having the predetermined doping concentration, the capacitance value of the semiconductor capacitor **14** changes less with an increase of the voltage applied to the semiconductor capacitor **14**, even though the semiconductor capacitor **14** operates in a depletion region and an inversion region. The capacitance value of the semiconductor capacitor **14** is substantially constant when the semiconductor capacitor **14** operates in an accumulation area. The semiconductor capacitor **14** having the predetermined doping concentration satisfies a formula:

$$R = \frac{C1 - C2}{C1} \leq 0.7,$$

where C1 is representative of the largest capacitance value of the semiconductor capacitor, C2 is representative of the smallest capacitance value of the semiconductor capacitor, R is representative of a ratio of C1 divided by a difference value of C1 minus C2. For different manufacturing condition, the doping concentration of the first well **140a** may be different. The doping concentration of the second well **140b** may be the same as a doping concentration of a capacitor well of a semiconductor capacitor manufactured under the same condition.

In the present embodiment, the n-type capacitor is described as an example of the semiconductor capacitor **14**. During a process of forming the n-type capacitor, for the second well **140b**, n-type ions are doped into the common well **12** once, and the second well **140b** is formed. For the first well **140a**, n-type ions are doped into the common well **12** at least two times, and the first well **140a** is formed. The n-type ions may be phosphorus ions, for example. Alternatively, a process of doping the n-type ion into the common well **12** for forming the second well **140b** and a process of doping the n-type ion into the common well **12** for forming the first well **140a** are carried out at the same time, and the manufacture conditions, such as the doping concentrations, may be same. Accordingly, the doping concentration of first well **140a** via doping the n-type ions into the common well **12** at least two times is higher than the doping concentration of second well **140b** via doping the n-type ions into the common well **12** once. In order to make the doping concentration of the semiconductor capacitor **14** reach the predetermined doping concentration, the doping concentration of the first well **140a** is correspondingly adjusted. However, a method of making the doping concentration of the high voltage capacitor **14** reach the predetermined doping concentration is not limited to the method of adjusting the doping concentration of the first well **140a**.

Similar to the above n-type capacitor, the P-type capacitor is not described in detail here.

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FIG. **3** is a voltage-capacitance curve of one of the semiconductor capacitors **14** of the semiconductor device **1**. In FIG. **3**, horizontal coordinates are representative of voltages applied between the top electrode plate **14b** and the bottom electrode plate **14a**, and longitudinal coordinates are representative of the capacitance values of the semiconductor capacitors **14**. The unit of the voltages is volt (V). The unit of the capacitance values is fF/um<sup>2</sup> and is represented by a letter "C". A curve "a" is a voltage-capacitance curve of the semiconductor capacitor **14**. A curve "b" is a voltage-capacitance curve of the semiconductor capacitor in the prior art. A voltage range [-1V, 0V] is representative of the voltages making a semiconductor capacitor operate in the depletion region. A voltage range [-13.5V, -1V] is representative of the voltages making a semiconductor capacitor operate in the inversion region. A voltage range [0 V, 13.5V] is representative of the voltages making a semiconductor capacitor operate in the accumulation region.

Because the doping concentration of the first well **140a** of the semiconductor capacitor **14** is much higher than the doping concentration of the first well of the semiconductor capacitor in the prior art, conductive particles on a surface of the bottom electrode plate **14a** increases when the voltage is applied to the semiconductor capacitor **14**. Accordingly, the capacitance value of the semiconductor capacitor **14** cannot decrease a lot, even though the semiconductor capacitor **14** operates in the depletion region and the inversion region.

As can be seen from FIG. **3**, when the semiconductor capacitor **14** operates in the depletion region and the inversion region, the capacitance value of the semiconductor capacitor **14** changes less with the change of the voltage applied to the semiconductor capacitor **14**. By the calculation, for the semiconductor capacitor **14**, R=0.3. In contrast, for the semiconductor capacitor in the prior art, R=0.715. Accordingly, for the semiconductor capacitor **14**, as long as R is less than 0.715 by adjusting the doping concentration of the first well **140a**, the stability of the capacitance value of the semiconductor capacitor **14** is improved.

In the present embodiment, for the semiconductor capacitor **14**, R is not more than 0.7 or 0.35. In detail, R may be 0.3, 0.4, 0.5, or 0.6, for example.

Since the doping concentration of the first well **140a** of the semiconductor capacitor **14** is much higher, the capacitance value of the semiconductor capacitor **14** can not decrease a lot, when the semiconductor capacitor **14** operates in the depletion region and the inversion region. Accordingly, the quality of the semiconductor capacitor **14** and the semiconductor device **1** employing the semiconductor capacitor **14** can be improved.

FIG. **4** is a partial perspective illustrating a second embodiment of a semiconductor device **2** according to the present disclosure. FIG. **5** is a top view of the semiconductor device **2** of FIG. **4**. The semiconductor device **2** differs from the semiconductor device **1** of the first embodiment in that semiconductor capacitors **24** of the semiconductor device **2** differ from the semiconductor capacitors **14** of the semiconductor device **1**. A plurality of isolation elements **26** spacing the semiconductor capacitors **24**, and an insulating layer **28** covering the semiconductor capacitors **24** and the isolation elements **26** of the semiconductor device **2** are shown in FIG. **4**, but not shown in FIG. **5**.

The semiconductor capacitors **24** are same with each other. One of the semiconductor capacitors **24** is described as an example. The semiconductor capacitor **24** includes a bottom electrode plate **24a**, a top electrode plate **24b**, and an

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insulating layer **24c** formed between the bottom electrode plate **24a** and the top electrode plate **24b**.

The bottom electrode plate **24a** includes a capacitor well **240** and a diffused region **242**. The capacitor well **240** includes a first well **240a** and a second well **240b**. The second well **240b** surrounds the first well **240a**. The diffused region **242** is formed above the first well **240a**, and does not overlap with the second well **240b**.

The top electrode plate **24b** and the insulating layer **24c** completely cover the second well **240b** and partially cover the first well **240a** in an X-Y plane shown in FIG. 5. One end of each of the top electrode plate **24b** and the insulating layer **24c** exceeds the second well **240b** along a first direction, the other end of each of the top electrode plate **24b** and the insulating layer **24c** is aligned with the second well **240b**. The first direction is a direction parallel to a Y-axis of the X-Y plane. The top electrode plate **24b** and the insulating layer **24c** cooperatively define an opening **245** positioned above the first well **240a**. The diffused region **242** is exposed from the opening **245** and does not overlap with the top electrode plate **24b** and the insulating layer **24c**. A shape and an area of the top electrode plate **24b** are same with a shape and an area of the insulating layer **24c**. The edge of the top electrode plate **24b** is aligned with the edge of the insulating layer **24c**. In this embodiment, the diffused region **242** only overlaps part of the first well **240a** as shown in FIG. 5.

Since the top electrode plate **24b** almost covers the capacitor well **240** except the diffused region **242** is exposed from the opening **245**, an opposite area of the top electrode plate **24b** to a bottom electrode plate **24a** is increased. Accordingly, a capacitance value of the semiconductor capacitor **24** is not only comparatively stable, but also is much larger than the semiconductor capacitor **14**.

In alternative embodiments, the doping concentrations of the second wells **140**, **240** instead of the doping concentrations of the first wells **140**, **240** are increased, to improve the stability of the semiconductor capacitors **14**, **24**. In addition, the doping concentrations of the first wells **140**, **240**, the second wells **140**, **240** are all increased.

The first wells **140a** and **240a** are formed on the common wells **12**, **22** respectively, but do not penetrate the common wells **12**, **22** respectively.

Although certain embodiments of the present disclosure have been specifically described, the present disclosure is not to be construed as being limited thereto. Various changes or modifications may be made to the present disclosure without departing from the scope and spirit of the present disclosure.

What is claimed is:

1. A capacitor, comprising:

a bottom electrode plate comprising a capacitor well and at least one diffused region formed on the capacitor well, a conduction type of the capacitor well being same with a conduction type of the at least one diffused region, and a doping concentration of the at least one diffused region is higher than a doping concentration of the capacitor well, the capacitor well comprising a first well;

an insulating layer formed on the bottom electrode plate; and

a top electrode plate formed on the insulating layer; wherein, the capacitance of the capacitor minor changes while operating in a depletion region or in an inversion region, the capacitance of the capacitor being operated in the different regions satisfies a formula:

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$$R = \frac{C1 - C2}{C1} \leq 0.7,$$

C1 is representative of a largest capacitance value of the C1 capacitor, C2 is representative of a smallest capacitance value of the same capacitor being operated in a depletion region or in an inversion region, R is representative of a ratio between a difference value of C1 and C2 and the smallest capacitance value of the capacitor C1, and a value of R is equal to or less than 0.7;

wherein the capacitor well further comprises a common well having a second conduction type and a second well surrounding the first well, the doping concentration of the first well is higher than a doping concentration of the second well; the second conduction type differs from the first conduction type, the common well is formed between the substrate and the capacitor, the first well penetrates the common well and is formed to resist on the substrate, and the second well is formed on the common well.

2. The capacitor according to claim 1, wherein  $R \leq 0.35$ .

3. The capacitor according to claim 2, wherein  $R = 0.3$ .

4. The capacitor according to claim 1, wherein the top electrode plate is formed above the first well.

5. The capacitor according to claim 4, wherein the at least one diffused region of the bottom electrode plate comprises two diffused regions, the two diffused regions are formed above the second well and are spaced from each other by the first well.

6. The capacitor according to claim 5, wherein the top electrode plate does not overlap with the two diffused regions.

7. The semiconductor device according to claim 1, wherein the at least one diffused region of the bottom electrode plate comprises a diffused region, and the diffused region is formed above the first well.

8. The capacitor according to claim 7, wherein the top electrode plate and the insulating layer cover the capacitor well and cooperatively define an opening above the diffused region.

9. The capacitor according to claim 8, wherein the top electrode plate and the insulating layer do not overlap with the diffused region.

10. A semiconductor device, comprising:

a substrate; and

at least one capacitor formed on the substrate, each of the at least one capacitor comprising: a bottom electrode plate comprising a capacitor well and at least one diffused region formed on the capacitor well, the capacitor well and the at least one diffused region each having a first conduction type, and a doping concentration of the at least one diffused region is higher than a doping concentration of the capacitor well, the capacitor well comprising a first well;

an insulating layer formed on the bottom electrode plate; and

a top electrode plate formed on the insulating layer; wherein, the capacitance of the capacitor minor changes while operating in a depletion region or in an inversion, such that each of the at least one capacitor satisfies a formula:

$$R = \frac{C1 - C2}{C1} \leq 0.7,$$

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C1 is representative of a largest capacitance value of the at least one capacitor being operated in an accumulation area, C2 is representative of a smallest capacitance value of the same at least one capacitor being operated in a depletion region or in an inversion region, R is representative of a ratio between a difference value of C1 and C2 and the smallest capacitance value of the capacitor C1;

wherein the capacitor well further comprises a common well having a second conduction type and a second well surrounding the first well, the doping concentration of the first well is higher than a doping concentration of the second well; the second conduction type differs from the first conduction type, the common well is formed between the substrate and the capacitor, the first well penetrates the common well and is formed to resist on the substrate, and the second well is formed on the common well.

11. The semiconductor device according to claim 10, wherein  $R \leq 0.35$ .

12. The semiconductor device according to claim 11, wherein  $R = 0.3$ .

13. The semiconductor device according to claim 10, wherein the top electrode plate is formed above the first

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well, the at least one diffused region of the bottom electrode plate comprises two diffused regions, the two diffused regions are formed above the second well and are spaced from each other by the first well.

14. The semiconductor device according to claim 10, wherein the at least one diffused region of the bottom electrode plate comprises a diffused region, the diffused region is formed above the first well, the top electrode plate and the insulating layer cover the capacitor well and cooperatively define an opening above the diffused region.

15. The semiconductor device according to claim 10, wherein the first conduction type is an n conduction type, and the second conduction type is a p conduction type.

16. The semiconductor device according to claim 10, wherein the first conduction type is a p conduction type, and the second conduction type is an n conduction type.

17. The semiconductor device according to claim 10, further comprising a plurality of isolation elements, wherein the at least one capacitor comprises a plurality of capacitors, and every two neighboring capacitors are spaced from each other by an isolation element and the common well.

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